PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference RS/pe-16072	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/CH 03/00243	International filing date *(day/month/year)* 11.04.2003	Priority date *(day/month/year)* 12.04.2002
International Patent Classification (IPC) or both national classification and IPC H02M3/337		
Applicant DELTA ENERGY SYSTEMS AG		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 9 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 8 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the opinion
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
12.11.2003	19.08.2004
Name and mailing address of the international preliminary examining authority: European Patent Office - P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk - Pays Bas Tel. +31 70 340 - 2040 Tx: 31 651 epo nl Fax: +31 70 340 - 3016	Authorized Officer Marannino, E. Telephone No. +31 70 340-3906

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/CH 03/00243

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, Pages

1-10 as originally filed

Claims, Numbers

1-35 received on 27.07.2004 with letter of 27.07.2004

Drawings, Sheets

1/6-6/6 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☒ the claims, Nos.: 36-41
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)).

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-35
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-35
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-35
	No:	Claims	

2. Citations and explanations

see separate sheet

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

Reference is made to the following documents:

D1: DE DONCKER R W ET AL: "A three-phase soft-switched high power density DC/DC converter for high power applications" 1988 IEEE, 2 October 1988 (1988-10-02), pages 796-805, XP010519176

D2: EP-A-0 430 242 (SYSTEL DEV & IND LTD) 5 June 1991 (1991-06-05)

The present international application relates to power conversion circuits and method to reduce reverse recovery losses in the secondary rectifiers, while primary switching elements switches at zero voltage.

Relating claim 1

Novelty

1. Document D1, which is regarded as being the closest prior art to the subject-matter of claim 1, discloses a power conversion circuit (Fig. 1) having a power transformer (L_m), four semiconductor switching elements (S1-S4) connected as a bridge across an input to the power conversion circuit and connected to a primary winding (in which Iprim flows) of the power transformer to reverse current trough the primary winding,
- a split secondary winding on the power transformer,

- a first unidirectional current conducting device (first diode connecting the secondary winding to the output C_o, R_o via inductor L_o) connected from a one end (+) of the split secondary winding to an inductor,

- a second unidirectional current conducting device (second diode connecting the secondary winding to the output C_o, R_o via inductor L_o) connected from a second end of the split secondary winding to the inductor,

- the inductor and a connection to an interconnection between two halves of the split secondary winding being connected to the output power conversion circuit (C_o, L_o),

- an injection voltage source (L_1, C_1) connected to the primary winding of the power transformer for applying an injection voltage to the primary winding in addition to an input voltage to the primary winding via the semiconductor switching elements.

The snubber capacitor C_1 is a voltage injection source since it provides a voltage in series with the primary winding of the transformer (L_m).

1.1 The subject-matter of claim 1 differs from this known power conversion circuit of D1 in that:
- the injection voltage source is an auxiliary transformer having a primary winding in series with the primary winding of the power transformer and a capacitor in series with a secondary winding of the auxiliary transformer and connected to ground.

The subject-matter of claim 1 is therefore new (Article 33(2) PCT).

Inventive step

1.2 The problem to be solved by subject-matter of claim 1 over D1 may be regarded as: to reduce the reverse recovery current.

1.2.1 Even if the skilled person would recognise the above mentioned problem which is also mentioned in D1 (see page 797, first column, lines 6-8), the skilled person would not be able to remove the injection voltage source of D1 consisting in the leakage inductor L_1 and the snubber capacitor C_1 and to substitute this element with the injection voltage source of claim consisting in **an auxiliary transformer** having a primary winding in series with the primary winding of the power transformer and a **capacitor in series** with a secondary winding of the auxiliary transformer and connected to ground.
On the contrary in D1 a completely different solution is given and the man skilled in art would not be prompted to abandon the teaching of D1.

1.2.2 Therefore subject-matter of claim 1 does involve an inventive step in the sense of Article 33(3) PCT.

1.3 Claim 2 is dependent on claim 1 and as such also meets the requirements of the PCT with respect to novelty and inventive step (Articles 33(2) and 33(3)).

Relating claim 3

Novelty

2. Document D2, which is regarded as being the closest prior art to the subject-matter of claim 3, discloses (fig. 12):

a power conversion circuit having:

- a power transformer (with one primary winding and two secondary windings) with at least primary winding and at least one secondary winding, a primary circuit (switch and primary winding of the transformer T1) connected with the primary winding and adapted to deliver a main primary current alternating in direction through the primary winding and adapted to deliver a main power secondary current from the secondary winding and to deliver electric power to a load,

- at least one semiconductor unidirectional current conducting device (D1a, D1b) in at least one of the primary and the secondary circuits and adapted alternately to conduct a main current passing through an associated one of the windings of the power transformer; comprising:

- an injection voltage source (T1) connected to apply a supplemental reverse bias voltage to the semiconductor unidirectional current conducting device sufficient to terminate forward conduction (induced by the current I_{R2}) (see column 3, line 31-58) in the device and to deplete carriers in the device **at the moment** when reverse current is flowing in the said device by an alternating of the main primary current causing a reversal of voltage across the associated power transformer winding.

2.1 Therefore subject-matter of claim 5 differs from the power conversion circuit of D2 in the fact that:

- the supplemental reverse bias voltage is sufficient to terminate forward conduction in the device at times **prior** to each reverse biasing

- the injection voltage source is an auxiliary transformer having a primary winding in series with the primary winding of the power transformer and a capacitor in series with a secondary winding of the auxiliary transformer and connected to ground.

The subject-matter of claim 3 is therefore new (Article 33(2) PCT).

Inventive step

2.2 The problem to be solved by subject-matter of claim 3 over prior art D2 may be regarded as: to find an alternative way of D2 in reducing reverse recovery current.

2.2.1 The man skilled art would not be able to modify the power conversion of D2 and combine the two new features which have a functional interrelation.

2.2.2 Therefore the man skilled in art would not arrive to teh subject-matter of claim 3 without using an inventive step.
The subject-matter of claim 3 is therefore new (Article 33(2) PCT).

2.3 Claims 4-22 are dependent on claim 3 and as such also meet the requirements of the PCT with respect to novelty and inventive step (Articles 33(2) and 33(3)).

Relating claims 23 and 28

Novelty

3. Document D2, which is regarded as being the closest prior art to the subject-matter of claim 23, discloses (fig. 12):

a power conversion circuit:

- having a power transformer (with one primary winding and two secondary windings) with a primary winding and at least one secondary winding having a semiconductor rectifying means (D1a, D1b) coupled in current conducting relation with at least one secondary winding, an inductor (L1a, L1b) coupled in current conducting relation between the semiconductor rectifying means and an output connection;

-an injection voltage source (T1) for applying a first, relatively low reverse bias voltage to the semiconductor rectifying means to halt forward conduction (induced by the current I_{R2}) (see column 3, line 31-58) and deplete carriers in the semiconductor rectifying means **at the moment** to each application to the semiconductor rectifying means of a reverse bias larger than the first relatively low bias voltage.

3.1 Therefore subject-matter of claim 23 differs from the power conversion circuit of D2 in the fact that:

- the injection voltage source applies low reverse bias voltage to halt forward conduction **prior** to each application to the semiconductor rectifying means of a reverse bias larger than the low bias voltage".

- the injection voltage source is an auxiliary transformer having a primary winding in series with the primary winding of the power transformer and a capacitor in series with a secondary winding of the auxiliary transformer and connected to ground.

The subject-matter of claim 23 is therefore new (Article 33(2) PCT).

Inventive step

3.2 The problem to be solved by subject-matter of claim 23 over prior art D2 may be regarded as: to find an alternative way of D2 in reducing reverse recovery current.

3.2.1 The man skilled art would not be able to modify the power conversion of D2 and combine the two new features which have a functional interrelation.

3.2.2 Therefore the man skilled in art would not arrive to teh subject-matter of claim 3 without using an inventive step.
The subject-matter of claim 23 is therefore new (Article 33(2) PCT).

3.3 Claims 23-27 are dependent on claim 23 and as such also meet the requirements of the PCT with respect to novelty and inventive step (Articles 33(2) and 33(3)).

3.4 The same reasoning applies mutatis mutandis to relative method claim 28 and dependent method claims 29-35.
Therefore the subject-matter of claim 28-35 meets the requirements of Articles PCT 33(2) 33(3).

Industrial applicability

4. The present power conversion circuits of independent claims 1, 3, 23, 26 find an application as power supplies therefore the industrial applicability of claim is beyond any

doubt.

Therefore independent claims 1, 3, 23, 26 meet the requirements of Article 33(4) PCT.

Reaming dependent claims also meet the requirements of Article 33(4) PCT.

What is claimed is:

1. A power conversion circuit having a power transformer, four semiconductor switching elements connected as a bridge across an input to the power conversion circuit and connected to a primary winding of the power transformer to reverse current through the primary winding, a split secondary winding on the power transformer, a first unidirectional current conducting device connected from one end of the split secondary winding to an inductor, a second unidirectional current conducting device connected from a second end of the split secondary winding to the inductor, the inductor and a connection to an interconnection between two halves of the split secondary winding being connected to an output of the power conversion circuit, characterised by an injection voltage source connected to the primary winding of the power transformer for applying an injection voltage to the primary winding in addition to an input voltage to the primary winding via the semiconductor switching elements connected as a bridge, where the injection voltage source is an auxiliary transformer having a primary winding in series with the primary winding of the power transformer and a capacitor in series with a secondary winding of the auxiliary transformer and connected to ground.

2. The power conversion circuit according to claim 1, wherein the unidirectional current conducting devices are semiconductor switching devices.

3. A power conversion circuit having a power transformer with at least one primary winding and at least one secondary winding, a primary circuit connected with the primary winding and adapted to deliver a main primary current alternating in direction through the primary winding, a secondary circuit connected to the secondary winding and adapted to receive a main secondary current from the secondary winding and to deliver electrical power to a load, at least one semiconductor unidirectional current conducting device in at least one of the primary and secondary circuits and adapted alternately to conduct a main current passing through an associated one of the windings of the power transformer; the improvement comprising:

an injection voltage source connected to apply a supplemental reverse bias voltage to the semiconductor unidirectional current conducting device sufficient to terminate forward conduction in the device and to deplete carriers in the device at times prior to each

reverse biasing of the device by an alternating of the main primary current causing a reversal of voltage across the associated power transformer winding, where the injection voltage source is an auxiliary transformer having a primary winding in series with the at least one primary winding of the power transformer and a capacitor in series with a secondary winding of the auxiliary transformer and connected to ground.

4. The power conversion circuit according to claim 3, wherein the at least one semiconductor unidirectional current conducting device comprises two such devices each connected in series with an associated secondary winding.

5. The power conversion circuit according to claim 3, wherein the injection voltage source is coupled to the at least one primary winding to develop across the at least one secondary winding a voltage producing across the semiconductor unidirectional current conducting device the supplemental reverse bias voltage.

6. The power conversion circuit according to claim 4, wherein the injection voltage source is connected in current conducting relation with the at least one power transformer primary winding to develop across each secondary winding of the power transformer associated with a semiconductor unidirectional current conducing device the supplemental reverse biasing voltage biasing each of the semiconductor unidirectional current conducting devices.

7. The power conversion circuit according to claim 5, wherein a current developed in the first winding of the auxiliary transformer is supplied through the at least one primary winding of the power transformer timed to generate a voltage in the secondary winding of the power transformer producing the supplemental reverse bias voltage.

8. The power conversion circuit of claim 3, wherein the at least one semiconductor unidirectional current conducting device comprises at least one rectifying diode connected in series with the at least one secondary winding between the at least one secondary winding and a load connection.

9. The power conversion circuit according to claim 8, wherein the at least one rectifying diode comprises a pair of rectifying diodes, each connected in series with at least one power transformer secondary winding.

10. The power conversion circuit according to claim 3, wherein the at least one semiconductor unidirectional current conducting device comprises at least one rectifying electrically controlled semiconductor switching device connected in series with the at least one secondary winding between the at least one secondary winding and a load connection.

11. The power conversion circuit according to claim 10, wherein the at least one electrically controlled semiconductor switching device comprises a pair of rectifying electrically controlled semiconductor switching devices, each connected in series with at least one power transformer secondary winding.

12. The power conversion circuit according to claim 10, wherein the at least one electrically controlled semiconductor switching device is a synchronous rectifier.

13. The power conversion circuit according to claim 11, wherein the pair of electrically controlled semiconductor switching devices is a pair of synchronous rectifiers, each connected in series with at least one power transformer secondary winding.

14. The power conversion circuit according to claim 4, wherein the power transformer has a pair of secondary windings each connected in series with one of the semiconductor unidirectional current conducting devices, the primary circuit comprises a circuit for delivering an alternating current through the at least one primary winding to produce alternating voltages across the secondary windings alternately biasing the semiconductor unidirectional current conducting devices into and out of conduction, the injection voltage source being a source of alternating voltage connected with the at least one primary winding of the power transformer to produce alternately in the pair of secondary windings a first supplemental reverse bias voltage reverse biasing a first of the pair of semiconductor unidirectional current conducting devices and a second supplemental reverse bias voltage reverse biasing a second of the pair of semiconductor unidirectional current conducting devices.

15. The power conversion circuit according to claim 14, wherein the at least one primary winding and the secondary windings of the power transformer are wound such that when the injection voltage produces the first supplemental reverse bias voltage reverse biasing the first of the pair of semiconductor unidirectional current conducting devices, the injection voltage also produces a first supplemental forward bias voltage forward biasing the second of the devices, and when the injection voltage produces the second supplemental reverse bias voltage reverse biasing the second of the semiconductor unidirectional current conducting devices, the injection voltage also produces a second supplemental forward bias voltage forward biasing the first of the devices.

16. The power conversion circuit according to claim 14, wherein the circuit for delivering an alternating current through the at least one primary winding comprises a plurality of electrically controlled unidirectional semiconductor switches connected in a bridge configuration between a DC input connection and the at least one primary winding of the power transformer.

17. The power conversion circuit according to claim 16, wherein the at least one primary winding of the power transformer and the injection voltage source are connected in series and connected to a junction of a pair of the electrically controlled unidirectional semiconductor switches to deliver a current to the junction of the switches, whereby substantially zero voltage switching of the switches is assured.

18. The power conversion circuit according to claim 14, wherein the circuit for delivering an alternating current through the at least one primary winding comprises a full bridge circuit coupled to the at least one primary winding and adapted to be connected across a DC source.

19. The power conversion circuit according to claim 18, wherein the full bridge switching circuit comprises four electrically controlled unidirectional semiconductor switches.

20. The power conversion circuit according to claim 19, wherein the four electrically controlled unidirectional semiconductor switches are electrically controlled to provide current in a first direction through the at least one primary winding, a short across the at least one primary winding and the injection voltage source, current in a reverse direction through the at least one primary winding, and then again a short across the primary winding and the injection voltage source, whereby the first and second secondary windings produce voltages of opposite polarities with intervening periods of a substantially lower voltage induced therein by the injection voltage.

21. The power conversion circuit according to claim 20, wherein the at least one primary winding of the power transformer is connected at one end to a junction of a pair of the electrically controlled switches, and in series with the injection voltage source, the injection voltage source being connected to a junction of a further pair of the electronically controlled switches, the at least one primary winding and injection voltage source delivering current substantially triangular in its plot of current versus time to the junctions of the pairs of electrically controlled switches to assure substantially zero voltage switching thereby.

22. The power conversion circuit according to claim 21, the injection voltage source producing substantially an AC square wave voltage.

23. A power conversion circuit having a power transformer with a primary winding and at least one secondary winding, an input circuit connected to the primary winding, an output circuit connected with the at least one secondary winding and having a semiconductor rectifying means coupled in current conducting relation with the at least one secondary winding, an inductor coupled in current conducting relation between the semiconductor rectifying means and an output load connection; the improvement comprising:

an injection voltage source for applying a first, relatively low reverse bias voltage to the semiconductor rectifying means to halt forward conduction and deplete carriers in the semiconductor rectifying means prior to each application to the semiconductor rectifying means of a reverse bias larger than the first, relatively low reverse bias voltage, where the injection voltage source is an auxiliary transformer having a primary winding in

series with the primary winding of the power transformer and a capacitor in series with a secondary winding of the auxiliary transformer and connected to ground.

24. The power conversion circuit according to claim 23, wherein the injection voltage source is connected with the primary winding of the power transformer to apply a supplemental voltage that is an alternating voltage producing in the at least one secondary winding of the power transformer the first, relatively low reverse bias voltage.

25. The power conversion circuit according to claim 24, wherein the semiconductor rectifying means comprises first and second semiconductor rectifying devices connected with first and second secondary windings of the power transformer, the auxiliary transformer applies an alternating voltage of first and second primary voltage levels to produce in the first and secondary windings first and second secondary voltage levels reverse biasing the first and second rectifying devices, respectively.

26. The power conversion circuit according to claim 23, wherein the semiconductor rectifying means comprises a pair of semiconductor unidirectional current conducting devices, and the injection voltage source for applying a reverse bias voltage alternately reverse biasing the semiconductor unidirectional current conducting devices and driving carriers from that device into the other, conducting unidirectional current conducting device.

27. The power conversion circuit according to claim 26, wherein the input circuit comprises a plurality of semiconductor switching means, connected with the power transformer primary winding and the injection voltage source, the injection voltage source being connected into the primary circuit to inject alternating current into the semiconductor switching means to assure substantially zero voltage switching thereof.

28. In a method of power conversion including switching a DC voltage to supply a power transformer primary, and rectifying with at least a first semiconductor rectifier a transformer output from a secondary of the power transformer; the improvement comprising applying to the semiconductor rectifier a relatively low reverse bias voltage to deplete at least one semiconductor junction of the semiconductor rectifier of carriers in advance of each

application to the semiconductor rectifier of a relatively high reverse biasing power transformer secondary voltage excursion, wherein applying to the semiconductor rectifier a reverse bias comprises applying an alternating injection voltage waveform to the primary of the power transformer to produce in a secondary of the power transformer the reverse bias voltage applied to the semiconductor rectifier, wherein applying an injection voltage comprises providing an auxiliary transformer having a first winding connected to the primary of the power transformer and having a second winding connected through a capacitor to ground.

29. The method according to claim 28, wherein rectifying with a semiconductor rectifier a power transformer output comprises rectifying the power transformer output with at least a second semiconductor rectifier; the improvement further comprising applying to the second semiconductor rectifier a relatively low reverse bias voltage to deplete at least one semiconductor junction of the second semiconductor rectifier of carriers in advance of each application of a relatively high reverse biasing power transformer secondary voltage excursion.

30. The method according to claim 29, wherein applying to the first and second semiconductor rectifiers a reverse bias comprises applying an alternating injection voltage waveform to the primary of the power transformer to produce in a secondary of the power transformer the reverse bias voltages applied to the first and second semiconductor rectifiers.

31. The method according to claim 29, further comprising applying to each semiconductor rectifier the reverse bias when the remaining semiconductor rectifier is conducting.

32. The method according to claim 31, wherein applying to each semiconductor rectifier the reverse bias comprises driving carriers out of the reverse biased rectifier and into the conducting rectifier.

33. The method according to claim 31, wherein applying the reverse bias further comprises applying the reverse bias to each semiconductor rectifier before application of a

higher voltage reverse biasing voltage thereto generated by the switched DC voltage supplied to the power transformer primary.

34. The method according to claim 28, further comprising supplying an alternating current to a semiconductor switching circuit that switches the DC voltage to supply the power transformer primary to assure zero voltage switching thereof.

35. The method according to claim 28, further comprising providing a full bridge semiconductor switching circuit as an input across the power transformer primary and a source of the reverse bias voltage, activating the switching circuit to apply as the input a first voltage of a first polarity and a second voltage of an opposite polarity and between each first and opposite polarity voltage, substantially no voltage.